

TWO-SLIT SPOT ANALYZER

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Abstract

The Two-Slit Analyzer is an instrument designed to simplify the task of making measurements of Cathode Ray Tube spot size. The working definition of spot size is the "width at the half-amplitude" of the energy distribution in the spot.

Distance calibration is built into the Two-Slit Analyzer. It is useful for making all of the many types of resolution measurements used in Cathode Ray Tube displays. Two-line raster, single-line raster, shrinking raster, bar chart resolution, spatial frequency response, linearity, phosphor noise, rise and decay time measurements can be made in addition to "width at half-amplitude".

The Two-Slit Analyzer is relatively simple to use, accurate and reliable. Operator decisions and eye fatigue are eliminated in measuring resolution.

A standard method for CRT spot measurements is suggested which will be useful in computer, radar, television and other types of information displays in defining performance of CRT's, deflection yokes, focusing coils, astigmatic correctors and associated devices which effect performance at the display interface.

Information Display systems using cathode ray tubes that require deflection yokes, focus coils, centering devices, deflection amplifiers, power supplies, signal generators and other components effect the resolution or the amount of information that the display system can handle in a given time.

Data display systems require increasing amounts of information presented in shorter time intervals; consequently, smaller spot sizes are required on the CRT face.

One of the system designer's problems is specifying the cathode ray tube and associated components to get the bits of information presented in a form, in sufficient quantity and in the required time.

The bits of information, in the form required, may be "round" spots or vectors generated by "round" spots on the face of the cathode ray tube. In order to determine how many bits of information may be contained in a line or how many lines in a raster, the designer must know the diameter of the CRT spot or width of the line. After consulting the various manufacturer's CRT data sheets, the designer observes that the spot diameter has been specified at the center of the tube, within 1/4-1/2 inch of some arbitrary geometric center, using either a shrinking raster method, spatial frequency response, two-line raster, or half-amplitude method to measure the spot size.

The CRT showing the smallest spot size or line width has a strong appeal to display designers required to produce state of the art information displays. The CRT with the smallest spot size consistent with cost considerations will probably be chosen.

After the display system has been assembled and turned on for photographic recordings, the 4" line on the face of the CRT that was designed to contain 4000 bits of data appears as a fuzzy line and there is no information available for the computer to do whatever computers do to bits of data.

As a designer of deflection yokes, my experience indicates that the cathode ray tube manufacturer has properly directed the wrath of his customer to the manufacturer of the

components that have degraded the well designed CRT electron beam. This is where the solution to our problems began.

The deflection yoke was designed to produce a uniform transverse deflecting field, and should not produce deflection defocusing; certainly with no current flowing in the windings the spot in the center of the CRT should not be effected. When measurements of spot size were made in our laboratory, usually it was found that the center spots were larger than the customer expected but the tube met the CRT manufacturer's specifications.

When the spot was deflected, spot distortions appeared; consequently, many thought that this proved that the deflecting fields were entirely to blame.

Currently, CRT and component designers recognize that the display on the face of the CRT is a result of the integration of magnetic and electrostatic fields from the CRT cathode to the CRT face including all of the peripheral components such as deflection yoke, focus coil, centering devices, shielding, position of components relative to electron beam trajectory, power supplies, operating procedures and ambient fields.*

After working on many of these typical situations, it became apparent that three factors had to be resolved:

- (1) Define spot size.
- (2) Measure spot size simply and objectively.
- (3) Relate all the various methods.

The Two-Slit Analyzer is an instrument that is finding increasing acceptance in many display applications around the world.

2.0 DEFINITIONS OF SPOT SIZE

2.1 GAUSSIAN ANALYSIS

The energy distribution in the CRT spot is very nearly Gaussian and all the power of Gaussian function analysis is applicable to the problem of spot size measurements. Many mathematicians, scientists and engineers have done the basic analysis, built equipment to verify theory with practice and published the results.

* High Resolution CRT's for Precision Display Systems
Dr. Hillary Moss, "Electronic Industries", April, 1954, Page 64

The Two-Slit Spot Analyzer was designed and built to provide a working instrument to measure accurately and simply the size of a cathode ray tube spot, particularly "the width at half-amplitude".

The Gaussian function is:

$$* y = e^{-\pi x^2} \quad (2.1)$$

One method of normalizing the function is to make the central ordinate and area under the curve unity. The Fourier Transform of the Gaussian is also Gaussian and is normalized exactly as above. The normalized form,

$$y = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \quad (2.2)$$

is called the "probability ordinate".

When the standard deviation is σ , the probability ordinate is:

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \quad (2.3)$$

The area under the curve remains unity.

Equation (2.3) is plotted in Figure 1 showing the pertinent parameters, (σ) and (w). (t) will be used later to measure linearity.

2.2 WORKING DEFINITION

"W", "Width at Half-Amplitude" is the working definition of spot size. The measurement is readily made for research, development, experimental or production testing. By choosing proper slit-lens combinations, spot sizes from 0.2 Mil to 50 Mils can readily be measured.

2.3 STANDARD DEVIATION

$\sigma = \frac{w}{2.35}$ standard deviation for Gaussian relationship. Some CRT manufacturers use σ as a spot-width definition or 1/2 width of Gaussian at 60% amplitude; others use 2σ , the full-width of the Gaussian at 60% amplitude.

2.4 SHRINKING RASTER METHOD

(Shrinking Raster Method) SRM has been widely used for TV resolution measurements.

When merging the lines in the SRM, the operator in compressing the raster is causing the Gaussian curves to overlap.

Since the eye scans the overall visible pattern for variation in the brightness of the field, the Spatial Frequency is increased (by SRM) and line to line spacing decreases. The human eye can detect about 3% difference in contrast. When the lines are further compressed, the pattern appears as a solid band of light. Consequently, one actually determines the 2% to 5% Spatial Frequency response point on the Spatial Frequency Curve. Bar chart resolution loss occurs at or near the extinction point of the spatial response curve.

Consequently, SRM yields line widths of one-half the width of the half-amplitude width.

Care must be taken in using the resolution data specified in CRT specifications so that it is applicable to your particular display.

2.5 BAR CHART RESOLUTION

A bar chart inserted into the slit holder of the Two-Slit Analyzer produces a modulation pattern relating the total light of the spot relative to the light available thru diminishing slit widths of increasing line pairs per unit length.

2.6 SPATIAL FREQUENCY RESPONSE

The Spatial Frequency method for determining resolution is analogous to the transient response of an electrical filter by determining the sine wave frequency response of the network. The frequency response is transformed into time domain characteristics using the Fourier integral.

2.7 EYEBALL MEASUREMENTS

Static measurements of spot size can be made by a skilled, trained, young technician.

Using a filar eyepiece graduated in microns, with X 150 power, subjective measurements are often valuable for CRT gun design, yoke evaluation and phosphor research.

Spot size on the 1 Mil spot of the example can be determined to be .9 to 1.1 Mil. (23 to 27 microns.)

A reference must be established subjectively, such as the "core" of the spot, ignoring halo. Repeated readings at various times under controlled ambient lighting conditions should be

* The Fourier Transform and Its Applications, Ron Bracewell, Page 54

compared with each other and repeated until the desired agreement is obtained.

The measured values will not be related to any absolute reference until calibrated with some objective measurement such as the two-slit half-amplitude.

2.8 DEFINITION CONFUSION

It can be seen that the designer of Information Display systems must be aware of the various definitions and how they apply to his selection of display components so that the situation described in the introduction is not repeated.

3.0 OPERATION OF TWO-SLIT ANALYZER

3.1 PURPOSE

Two Gaussian curves were plotted in Figure 1 of the function $e^{-\pi x^2}$. The purpose of the Two-Slit Analyzer is the automatic production of the two Gaussian distribution curves of the light energy in the CRT spot as shown in the Oscillogram of Figure 4a. The spot width at the half-amplitude is read directly on the Oscilloscope graticule at one-half the ordinate height.

3.2 DESCRIPTION

Figure 2 is a schematic of the Two-Slit setup. The ramp generators with D.C. positioning supply the deflection amplifier input which is converted to current to drive the deflection yoke. The spot on the face of the CRT is scanned horizontally. An enlarged diagram of the scanned spot on the CRT face is shown at (A).

The microscope with objective (B) focuses the scanning spot on the slit plane (C). The slits are accurately machined in a metal composition disc which is placed into a slit holder. The slits and holder are supported in a goniometer which allows the slits to be rotated thru an arc of 180° . The goniometer (slit rotator calibrated in degrees) and the capability of changing scan directions with the X-Y ramp generators and X-Y deflection amplifiers with D.C. biasing, makes it convenient to examine the spot for astigmatism anywhere on the CRT face. An X-Y traverse provides accurate mechanical positioning of the Two-Slit Analyzer.

The scanning spot, focused on slit plane (C), traverses the slits and the light that passes

thru the slits from the particular section of the enlarged spot at any instant is picked up by the photomultiplier tube, PMT. The sequence is shown in (D).

The light is converted into an electrical output which is proportional to the light intensity or energy in the spot section. The PMT voltage is fed to the amplifier of an Oscilloscope and by the time base being triggered with the ramp generator and setting the time base to correspond to the calibration of the Two-Slit Analyzer a distance reference is established between the two peaks of the two Gaussians, one each, produced by each of the two slits.

The ordinate is established by adjusting the Oscilloscope amplifier gain to fill the Oscilloscope graticule when the CRT is focused to give maximum PMT output.

When these adjustments have been made, the spot width is read directly on the graticule at the half-amplitude point. The horizontal positioning control permits the observer to place one of the Gaussian curves at a convenient point on the graticule and read the width at the half-amplitude directly in Mils.

Figure 3 is a photograph of the Two-Slit Analyzer, X-Y traverse with Z focus and CRT mount with yoke, focus coils and centering coils with appropriate micropositioners for adjusting the magnetic components properly relative to the electron beam trajectory.

3.3 MEASUREMENT

Figure 4a shows an Oscillogram of a measurement using a 5" flat face CRT with P16 phosphor.

The time base on the Oscilloscope was adjusted ($20 \mu\text{s}/\text{cm}$) so that the two Gaussian peaks coincide with the instrument calibration; in this case, $1 \text{ cm} = .001''$ or 6 cm for $.006''$ which is the constant for the slit-magnification combination. The vertical gain of the Oscilloscope was adjusted so that the ordinates of the Gaussians just fill the graticule on the face of the Oscilloscope, $5 \text{ mv}/\text{cm}$. The width of the spot (W) may be read directly on the graticule at the half-amplitude of the ordinate since $1 \text{ cm} = .001''$, in the case of Figure 4a.

Since the calibration is made at the factory, it is not necessary to make any calibration measurements on the CRT face under observation.

This is one of the advantages of using two slits. If a new objective lens is required for a new set of slits to measure other ranges of spot size, a stage micrometer (an accurately ruled scale on glass) with calibration procedure is provided for calibration in the fields.

3.4 CALIBRATION

In Figure 2D consider the spot at slit number 1 to be stationary at a low beam intensity. With the Two-Slit mounted on the X-Y traverse or other traveling measuring machine, the distance calibration is as follows:

- (1) Move Analyzer so spot is centered in slit number 1. This is indicated for maximum output on the oscilloscope. The X distance reading is recorded.
- (2) Move the Two-Slit Analyzer slit to the spot centered in number 2 slit. This position is indicated by a second peaking in scope output. The X distance is again recorded.
- (3) The difference is the actual distance that the microscope "sees" on the CRT face.
- (4) This distance is then used to choose a convenient time base scale.
- (5) In the Oscillogram of Figure 4, the distance was $0.0060 \pm .0001$ inches as established on the Celco measuring machine, direct reading to 0.000025". The time base vernier was adjusted so the peaks of the Gaussian curves were 6 cm apart corresponding to the 0.006" on the CRT face. Using the two slits establishes a distance reference on the Oscilloscope which is easy and convenient to read.

3.5 ASTIGMATISM

In section 3.2 the CRT spot was focused for maximum ordinate height on the Oscilloscope graticule and the vertical gain was adjusted to just fill the full height of the scale. This would be the focused condition only if the CRT spot were absolutely round. That is, the spot was anastigmatic. Figure 2E shows the condition for maximum ordinate focus for a spot with astigmatism causing the spot to be stretched in the vertical direction.

Rotating the slits 90 degrees and scanning normal to the slits, without changing focus, would show increased spot size as in 2F with

the Oscillogram sketched below.

In order to make rapid rough evaluations of these conditions, an eyepiece was built into the Two-Slit Analyzer as pictured in Figure 3. A mirror is positioned in the microscope body so the CRT spot may be viewed directly thru a 50X microscope and measurements estimated on a graticule in the eyepiece.

When a system exhibits astigmatism in a random display and there is no possibility for correction, then the focus adjustment must be made so that there is no change in spot size for the orthogonal spot width measurements. This is focus condition for the "best" round spot.

4. RELATED SPOT SIZE MEASUREMENTS

4.1 ARGUMENT

Why should the spot size be defined as the width at half-amplitude as a "working definition" when

- (A) The TV industry has used the "shrinking raster method" (SRM) for at least 30 years.
- (B) The "Spatial Frequency Response" method is cited in the literature and used for system analysis. Some CRT manufacturers specify their performance in terms of the "SFR".
- (C) "Bar Chart Resolution" (BCR) has been used by engineers for years in evaluating photorecorded displays. Figure 4b.
- (D) The "Eye Ball Method" (EBM) is used by more engineers than any other method.
- (E) The "Two-Line Raster" (TLR) method of Larry White of Westinghouse was described in 1960. Figure 4c.
- (F) The "Two-Slit Single Line" (TSSL) raster of Celco is a variation of (E). Figure 4f.

All of these methods yield the same results, if interpreted realistically, based on confirmed theoretical analysis. The Two-Slit Analyzer can be used for all of the above measurements but the "width at the half-amplitude" is simple to measure under specified conditions with the minimum of peripheral equipment.

The other methods can either be measured directly or calculated from the Gaussian curves.

As an example of interpretation of CRT specifications for line width based on shrinking raster

method, a theoretical and experimental analysis may help clarify some general misunderstanding.*

The shrinking raster test (SRM) is made as follows:

4.2 SHRINKING RASTER ANALYSIS

A TV raster is presented on the CRT and the number of visible lines taken as the number of lines in the display. The vertical gain or picture height is reduced until the lines in the raster, as viewed in a microscope, appear to be merged; i.e., the field just becomes a uniform brightness. The height of the raster is measured and is divided by the number of visible lines in the raster. The answer is taken as "line width". This is a simple measurement to make particularly if you have a TV set-up.

It has become a common erroneous practice to assume the "line width" to be the half-power point of the Gaussian distribution.

Since the eye scans the overall visible pattern for any variation in the brightness of the field, the Spatial Frequency is increased (by SRM) and line to line spacing decreases. The human eye can detect about 3% difference in contrast. When the lines are further compressed, the pattern appears as a solid band of light. Consequently, one actually determines the 2% to 5% Spatial Frequency response point on the Spatial Frequency Curve. Bar chart resolution loss occurs at or near the extinction point of the spatial response curve.

Consequently, SRM yields line widths of one-half the width of the spot at half-amplitude width.

Care must be taken in using the resolution data specified in CRT specifications so that it is applicable to your particular display.

If a 1 Mil line was obtained using the SRM and one assumed 1000 bits of information per inch, a 50% error would be involved; that is, only 500 bits of half-amplitude data would be available.

The shrinking raster appears homogenous when the two Gaussian shaped functions overlap

sufficiently to yield an incremental flux Δ .

From Equation (2.3)

$$\left. \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \right|_{x=0} - \left. \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \right|_{x=x_0} = \Delta \quad (4.1)$$

in decimal terms

$$1 - 2e^{-\frac{x_0^2}{2\sigma^2}} = \frac{\Delta}{\frac{1}{\sigma\sqrt{2\pi}}} = \delta \quad (4.2)$$

$$\frac{1-\delta}{2} = e^{-\frac{x_0^2}{2\sigma^2}} \quad (4.3)$$

$$-\frac{x_0^2}{2\sigma^2} = \ln \left(\frac{1-\delta}{2} \right) \quad (4.4)$$

$$\sigma^2 = -\frac{x_0^2}{2 \ln \left(\frac{1-\delta}{2} \right)} \quad (4.5)$$

Considering the spatial frequency situation, a new function is generated through the convolution of a positional representation with a Gaussian shaped spreading (illuminating) operator, the Fourier Transform of the spreading function as the system response of a wide-band stimulus. Then

$$\mathcal{F}\left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}\right) = e^{-\frac{\sigma^2\omega^2}{2}} \quad (4.6)$$

$$G(\omega) = e^{-\frac{\sigma^2\omega^2}{2}} = e^{-\frac{\sigma^2\frac{1}{2\pi} \pi^2 f^2}{2}} \quad (4.7)$$

* High Resolution Cathode Ray Tube Evaluation ASD-TDR-63-796, Section II

$$G(\omega) = e^{-\sigma^2 2\pi^2 f^2} \quad (4.8)$$

ω = Radians/linear dimension or 2π x cycles/linear dimension

Sub. (σ^2) from (4.5) into (4.6)

$$G(\omega) = e^{-\frac{\omega^2}{2} \frac{X_0^2}{2 \ln(1-\delta)}} \quad (4.9)$$

Since raster appears homogenous at $X = X_0$, the line spacing is $2X_0$

$$L = \frac{1}{2X_0} \quad (4.10)$$

$$\begin{aligned} G(\omega) & \text{ at } \\ \omega &= 2\pi L = \frac{\pi}{X_0} \end{aligned} \quad (4.11)$$

$$G(\omega) = e^{-\frac{\pi^2}{4 \ln(1-\delta)}} \approx e^{-\frac{2.46}{\ln(1-\delta)}} \quad (4.12)$$

Since the eye can distinguish about a 3% difference in illumination level, presume $\delta = 0.03$ (4.13). Then

$$\begin{aligned} G(\omega) & \Big|_{\omega=2\pi L} \approx e^{-\frac{2.46}{\ln 0.485}} \approx e^{-3.4} \approx 0.034 \quad (4.14) \end{aligned}$$

and resolution is lost at a line frequency corresponding to approximately 3.4% response point on the spatial frequency response curve.

The shrinking raster test produces results directly related to the cut-off frequency of the spatial frequency response curve and not to the "half-power" point. Experimental data verify these results. Half-amplitude width (W) is

about twice the width obtained by SRM.

4.3 STANDARD DEVIATION

Another case of misinterpretation is for spot diameter given in terms of σ . Figure 1 and Equation (4.15) shows the relationship.

$$W = 2.35\sigma \quad (4.15)$$

Consequently, if the spot size were specified as σ , bits of information in the desired quantity would not be available unless the proper interpretation were made.

4.4 SPATIAL FREQUENCY RESPONSE

Spatial Frequency Response is another powerful and important method for defining the resolution of a system.

The Spatial Frequency method for determining resolution is analogous to the transient response of an electrical filter by determining the sine wave frequency response of the network. The frequency response is transformed into time domain characteristics using the Fourier integral.

This aperture method requires that the cathode ray tube have a raster generated on the face of the tube. The control grid of the cathode ray tube is modulated with a sine wave oscillator. When the frequency of the modulating signal is slightly higher or lower than some multiple of the vertical frame rate of the raster, a standing wave pattern will slowly drift in the vertical direction. The frequencies of the modulating signal are chosen so that the drift frequency remains constant at all test frequencies throughout the entire test.

The modulating frequencies are determined by the following equation:

$$f_m = m f_f \pm f_d \quad (4.16)$$

f_f = freq. vert. frame rate

m = any multiple of

f_d = the desired drift rate

f_m = the frequency of the Modulating Signal

The pattern of the raster is received by a photomultiplier tube through a very narrow slit thru a microscope. Figure 5 is a block diagram of this method showing that the output of the photomultiplier tube is a series of amplitude

modulated pickets whose envelope frequency is the vertical frame rate of the raster. The sine wave modulation has a frequency equal to the drift frequency. The output of the photomultiplier is fed to a low pass filter.

The output of the low pass filter yields the sine wave modulating signal by itself. The amplitude of the signal is measured by a vacuum tube voltmeter and monitored by the Oscilloscope as shown in Figure 5.

During this test the amplitude of the filter output is recorded along with the modulating frequency at each test frequency. The test frequency is then converted in terms of spatial frequency by:

$$N = \frac{2 f_m UN}{f_f l} \quad (4.17)$$

N = Spatial Frequency in TV lines per inch

f_m = The modulating frequency in Hz

f_f = Vertical frame rate in Hz

l = Visible vertical length of raster in inches

UN = Normalized Unblanked Time

Amplitude of filter output is normalized with respect to amplitude of the lowest spatial frequency of test.

A normalized amplitude spatial frequency curve can be graphed from the recorded data and the data can also be used to obtain the spread function of the CRT spot and the equivalent band pass "the ideal rectangular noise band pass". The spatial frequency curve can then be Fourier Transformed graphically into the spread function.

The spatial frequency response is useful in cases where overall system performance must be predicted. If each element in the system yields a SFR number at some frequency or line pairs or cycles per linear unit, then the net spatial frequency response is the product of the individual elements.

4.5 COMPARISONS

As we have seen, the many methods of measuring and specifying spot size are related. However, the appeal of the "width at half-amplitude" definition and simple measurement procedure with a commercially available instrument, that does not depend on eyeball characteristics or operator decision may be a candidate as a "standard".

Typical Measurements on a High Resolution 42° CRT with P16 Phosphor

- (1) w = Spot Width at Half-Amplitude
= 1.0 Mil
- (2) σ = Spot Half-Width at 60% Amplitude
= 0.43 Mil
- (3) Shrinking Raster Method (SRM) = 0.5 Mil
- (4) Bar Chart Resolution 50% Modulation
≈ 600 Elements/Inch
- (5) Bar Chart Resolution Loss ≈ 1400 Elements/Inch
- (6) Spatial Frequency Response (Extinction)
= 830 Cycles/Inch
- (7) Spatial Frequency @ 60% = 380 Cycles/Inch
- (8) Eyeball measurement by selected trained young operator .9 Mil to 1.1 Mil
- (9) Linearity: Transit Time "t" for spot to traverse slits.

In any measuring system there are limitations and the instrument user must be aware of the conditions under which the measurements are made and which extrapolations are possible.

5.0 LIMITATIONS

5.1 BAND WIDTH

Now that spot size has been defined and measured under certain conditions, spot velocity as related to phosphor rise and decay time and the band width requirements of the measuring system must be considered.

Figure 6 shows curves of apparent spot size vs spot velocity using P-11 and P-16 phosphors as measured with the Two-Slit Spot Analyzer. Initial spot diameter at half-amplitude was 1.4 Mil for both CRT's. The scope amplifier band width was 28 mc minimum. The curves show that at fairly low velocities, at 100 inches per second, the P-11 phosphor CRT shows a 10% apparent spot growth. The P-16 phosphor does not "grow" below 1000 inches per second.

The transit time of the P-16 spot past the slits becomes too short to permit the phosphor to decay and the light from both slits is integrated to cause an apparent widening of the spot. This is certainly true of the P-11 phosphor but not necessarily the case for the P-16.

In order to extract the "information" in the spot, the faster it moves, the higher the frequency components; consequently, the greater band

width requirements of the PMT circuit, transmission line and CRT amplifiers.

Rewriting Equation (4.6)

$$f\left(\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{x^2}{2\sigma^2}}\right) = e^{-\frac{\sigma^2\omega^2}{2}} = G(\omega) \quad (5.1)$$

$$G(\omega) = e^{-\frac{\sigma^2\omega^2}{2}} \quad (5.2)$$

ω = Radians per Linear Dimension or $2\pi \times$
Cycles per Linear Dimension

$$G(\omega) = e^{-\frac{\sigma^2 2\pi^2 f^2}{2}} \quad (5.3)$$

$$G(\omega) = e^{-\sigma^2 2\pi^2 f^2} \quad (5.4)$$

If

f_s = Frequency in Cycles per Inch

σ = Normal Deviation of Spot in Inches

$R(f_s)$ = The one dimensional Fourier Transform of the Gaussian distribution (f_s)

$$R(f_s) = e^{-2\pi^2 f_s^2 \sigma^2} \quad (5.5)$$

If spot size is taken as the distance at half-amplitude: From Equation (2.5)

$$W = 2.35\sigma \quad (5.6)$$

$$R(f) = e^{-\frac{2\pi^2 f^2 W^2}{(2.35)^2}} \quad (5.7)$$

For a sweep of V inches/second, the frequency f_t in cycles per second is:

$$f_t = f_s V \quad (5.8)$$

$$R(f_t) = e^{-\frac{2\pi^2}{(2.35)^2} f_t^2 \frac{W^2}{V^2}} \quad (5.9)$$

An approximation to the band pass, B , required to pass these frequencies

$$B \approx \frac{V}{W} \quad \text{in Cycles per Second} \quad (5.10)$$

$$\text{This is where } R(f_t) \approx 0.1 \quad (5.11)$$

For 100 in/sec writing speed for a 0.0014" spot.

$$B \approx \frac{100}{0.0014} \approx 71 \text{ KHz} \quad (5.12)$$

and for 1000" per Second

$$B \approx \frac{1000}{0.0014} \approx 0.71 \text{ MHz} \quad (5.13)$$

Additionally,

Spot Velocity Inches/Second	Spot Diameter Inches	Band Width Required
100	.0014	71 KHz
1000	.0014	.71 MHz
10,000	.0014	7.1 MHz
100,000	.0014	71 MHz

In Figure 7

R_L , the load resistance on the photomultiplier on the standard instrument is 1K ohm. The band-width is approximately .7 MHz. Consequently, curves of Figure 8 indicate that band width is causing a larger apparent spot size for the P-16 phosphor.

Using a lower value of R_L , 100 ohms, makes it possible to measure spot velocities to 10,000-50,000 inches per second. (See Figure 6, Curve 3).

The usual compromises must be made between gain and band width. As more current is drawn from the PMT, less voltage is available to drive the Oscilloscope.

For higher spot velocities the line width measured to the half-amplitude point using the single-line, Two-Slit Analyzer method, makes it possible to measure spot velocities over 100,000 inches per second.

The band width of the Oscilloscope and its sensitivity must be adequate as indicated in the chart above. As spots become smaller, the bandwidth-gain problem becomes more critical.

5.2 PHOSPHOR LOADING

The Two-Slit Analyzer is useful in making spot size measurements vs. velocity at constant phosphor energy loading and measuring the relative light output of the PMT.

The phosphor energy loading for watts/second/sq. cm=constant makes possible the comparative radiance measurements.

Figure 8 is a plot showing (upper curve) the variation of spot radiance with spot velocity. The lower curve shows spot size increase with velocity for the band width limited condition for a P-16 phosphor and a 0.0014" spot.

Under various phosphor loading conditions the phosphor rise and decay times may be measured as indicated in Figure 4d. Phosphor and/or face noise may also be examined in Figure 4e.

No correlation has been made between noise and resolution but it is hoped that the phosphor researchers and glass manufacturers will find the Two-Slit Analyzer a tool for their endeavors.

6.0 CONCLUSIONS

6.1 GAUSSIAN DISTRIBUTION

When the distribution of the energy in the CRT spot is Gaussian, all of the Gaussian function analysis techniques are applicable for making calculations relating the parameters of the spot characteristics. The energy distribution in the CRT spot is nearly Gaussian.

Variations in energy distribution of the CRT spot would still allow measurements to be made at the "half-amplitude", by definition.

The Two-Slit Spot Analyzer is a measuring instrument, that in addition to its basic function of measuring spot size at half-amplitude, has many additional functions and advantages. The basic function of half-amplitude measurement should be a factor in considering the instrument as a "standard".

6.2 ADVANTAGES

The ultimate merit of the Two-Slit Spot Analyzer is enhanced by the many uses and safety features for operating personnel. A listing of the factors in no particular order of importance is presented below to give the display engineer a ready check list that may relate to some phase of his work.

- (1) "Width at half-amplitude" is a convenient definition for defining spot size.

- (2) When the energy distribution is Gaussian, mathematical analysis with a long historical background is applicable. Currently popular statistical procedures are available for determination of operating parameters.
- (3) The Two-Slit Spot Analyzer is easy to use.
- (4) The measurements are accurate and repeatable.
- (5) Only distance standards are required for basic calibration.
- (6) Stage micrometers make field calibration practical for addition of new objectives, slits, charts and other configurations in the slit holder.
- (7) All other types of resolution and spot measurements can be made by additional peripheral equipment.
- (8) Modular expansion of measuring laboratory.
- (9) Additional measurements and uses:
 - (a) Phosphor Rise and Decay Time
 - (b) Phosphor Noise
 - (c) Phosphor Loading
 - (d) Linearity of Ramps and CRT Face Distortion
 - (e) Relative Radiance
 - (f) Camera Tube Performance (Investigating)
 - (g) Probability Function Generator for Computer Uses (Investigating)
- (10) Wide Range of Spot vs Velocity, Line Width vs Velocity
- (11) Range of Spectral Responses (Investigating)
- (12) Wide range of spot sizes can be measured approximately 5 microns to 1250 microns (.0002" to .050").
- (13) Astigmatism Measurements on the Spot and Evaluation of Components Contributing to Distortion.
- (14) Eliminates fatigue to operator's eyes.
- (15) Reduces radiation hazard from X-rays since operator does not have to keep his eyeball focused on a microscope close to CRT face.
- (16) Minimizes injury to personnel working in the vicinity of CRT's.
- (17) Eliminates the ambiguities between measurements performed by different operators.
- (18) Minimum of skill required to make spot size measurements. Eliminates long break in time to replace experienced technicians who have left for other jobs.
- (19) Read out device is standard Oscilloscope

- available in every electronics laboratory.
- (20) Small and Compact - Easily Storable in Case
 - (21) No operator decision as to when the raster is merged or where are the boundaries of the spot? Simply read at "half-amplitude".

6.2 DISADVANTAGES

- (1) Cannot "look" at an existing standard display and give a resolution number. (We are working on a unified theory of displays to define performance of a display system.)
- (2) Band Width Limitations
- (3) Spot Velocity Limitations
- (4) Some low efficiency phosphors do not have sufficient luminance to produce useful signals from PMT's. (Here, new PMT's and spectral responses under investigation.)
- (5) Cost considerations place the equipment out of the reach of the casual user.

6.3 PRESENT AND POTENTIAL USERS

The most important classification of Two-Slit Analyzer users to date have been cathode ray tube users who wanted to know why their systems were not performing as they designed them.

When they found out and the engineers realized that specifications are not always what they seem, it became important "to make the words mean what they wanted them to mean".*

As a result, the manufacturing and inspection departments of sophisticated display systems used the Two-Slit Analyzer with X-Y traverse as a line up and control instrument.

Procurement of CRT, yokes, etc. was predicated on Two-Slit Spot size measurements. This tends to separate various component manufacturers into classifications. That is, for certain resolution and phosphor performance some manufacturers have techniques that are superior for specific parameters. The same is applicable to yoke, focus coil, and other magnetic deflection components.

- (A) Improvement of Component Performance by Two-Slit Spot Analyzer Analysis
- (B) Military, NASA, Air Force, Navy, Army, Signal Corps, Research and Development of Precision Radar, Photogrammetry
- (C) Commercial Research into Molecular and Microcircuit Techniques.
- (D) Cathode Ray Tube Manufacturers Engaged in the More Modern Advanced Industrial, Military, Space and Commercial Applications; Phosphor Research and Quality Control of CRT's
- (E) Universities Engaged in Extending the State of the Display Art
- (F) Institutions Involved in Electronic Graphic Arts Applications

The Two-Slit Spot Analyzer is a measurement instrument that finds use wherever cathode ray tube displays are researched, designed, built and used.

The versatility of the instrument is continually being expanded for new applications and other novel uses.

7.0 ACKNOWLEDGEMENTS

The Celco Two-Slit Analyzer was designed by Peter M. Constantine and the oscillograms were made by Milton Farber, members of the Celco Engineering Department. The numerical machine programming for producing the Two-Slit Analyzer was supervised by Pano M. Constantine, General Manager of Celco, Mahwah, New Jersey Division.

* Lewis Carroll - Through A Looking Glass

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Philco, Lansdale, Pa.
RCA, Harrison, N.J.
Raytheon, Quincy, Mass.
Sylvania Elect. Corp., Seneca Falls, N.Y.
ETC, Philadelphia, Pa.

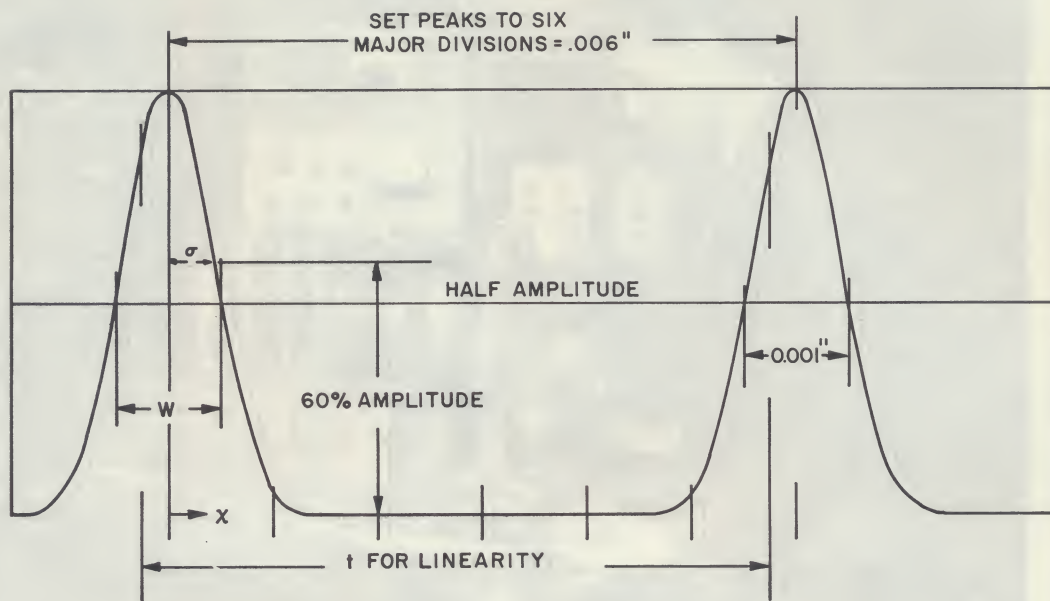


FIGURE 1

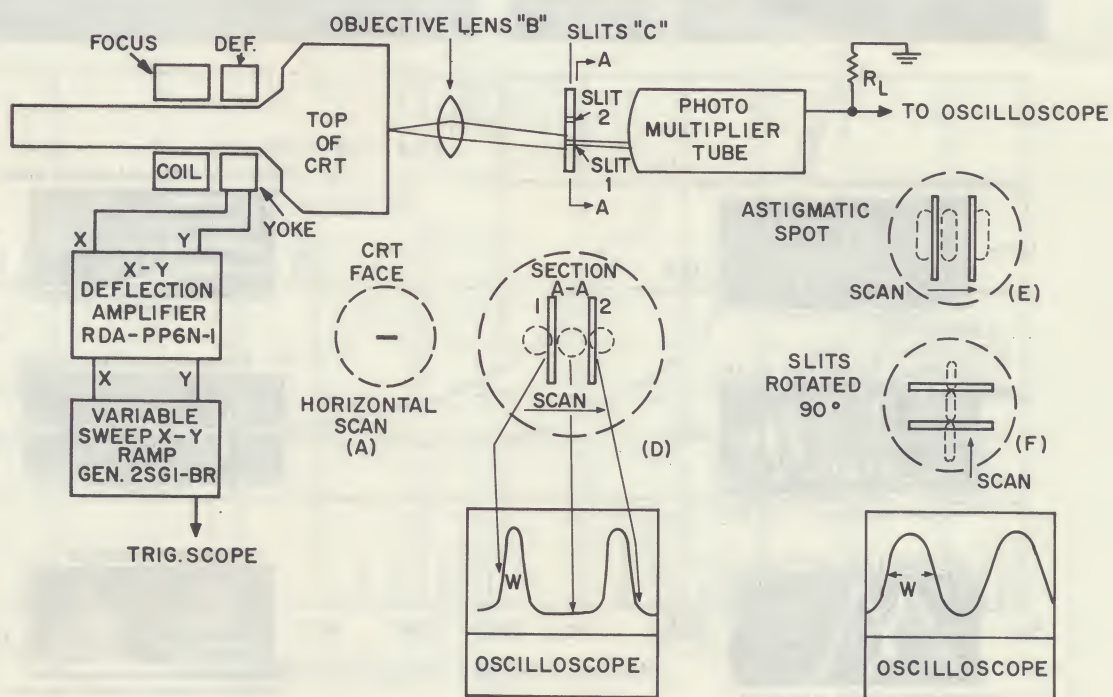
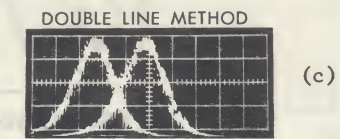
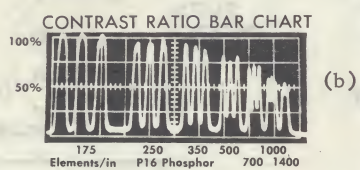
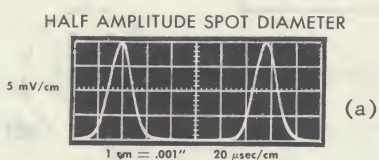
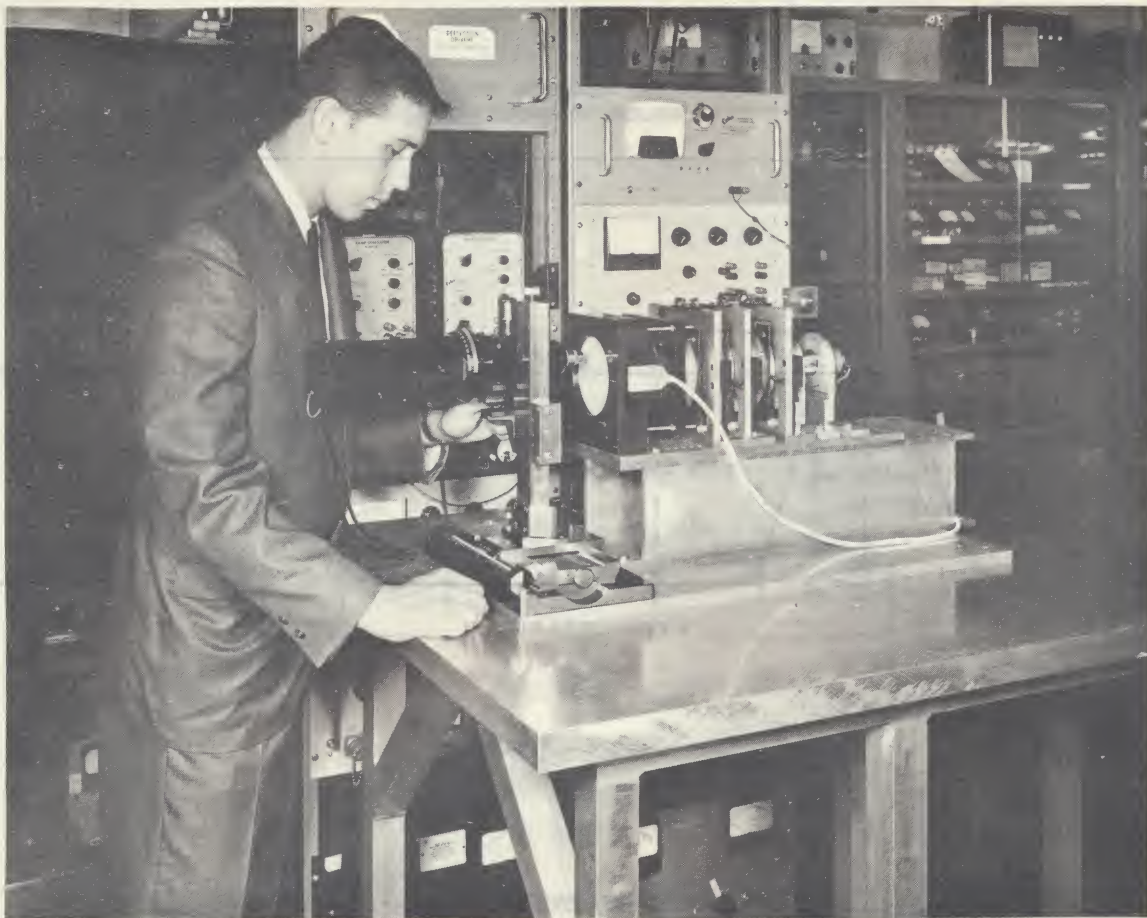
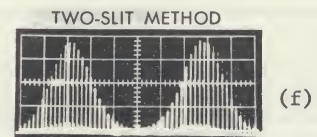
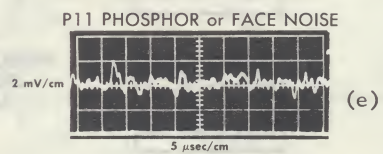
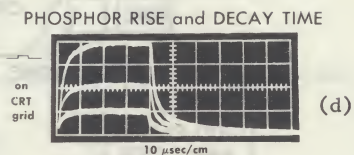


FIGURE 2



(2 line raster parallel to single slit)
3 sweep signals needed, raster must be moved vertically. Measurement of line spacing must be made on CRT face



(Single line raster parallel to slit pair)
Only 2 sweep signals required.
Distance calibration is locked into analyzer. No measurement on CRT face

FIGURE 4

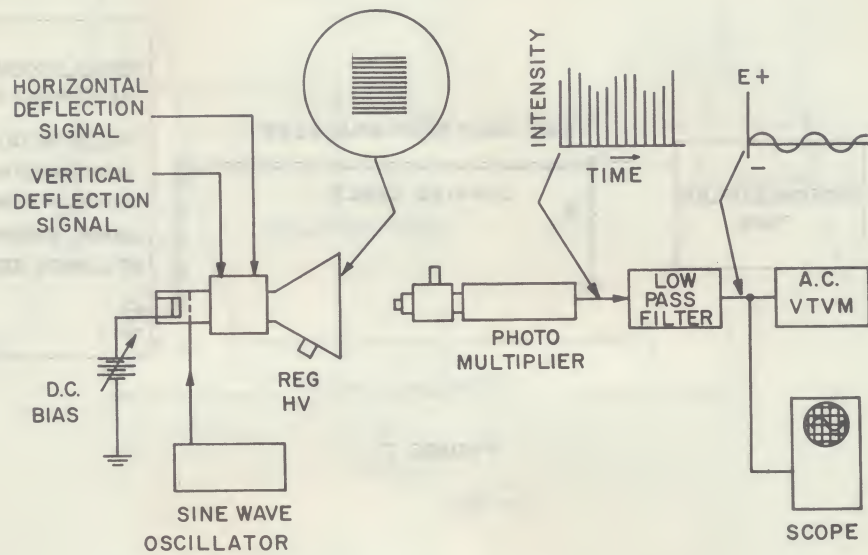


FIGURE 5

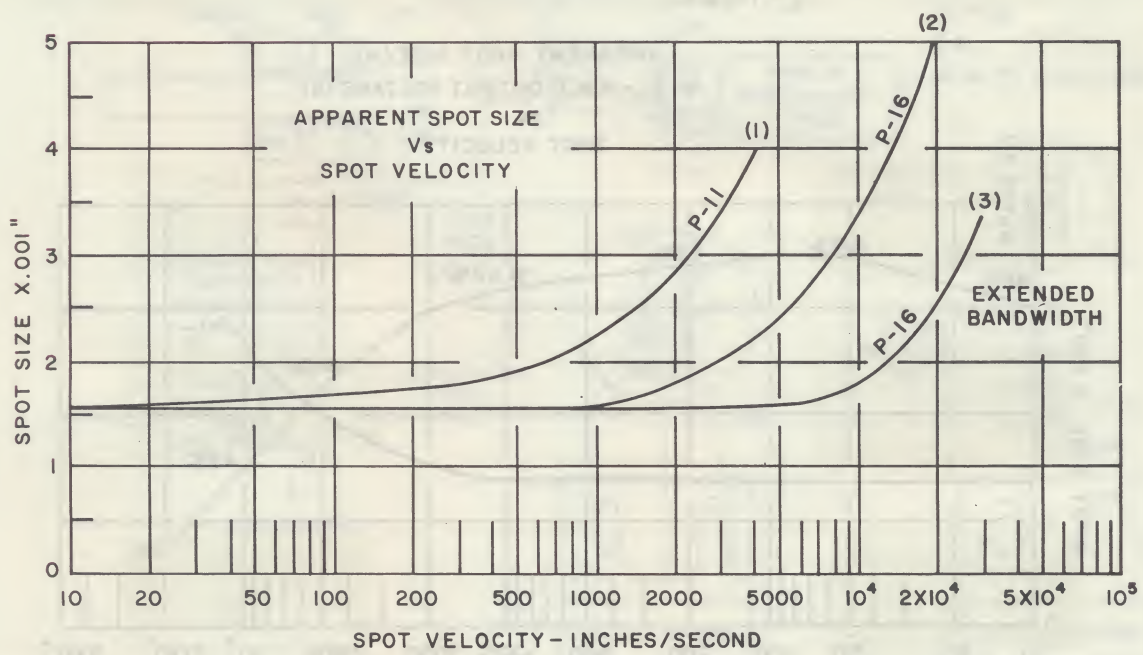


FIGURE 6

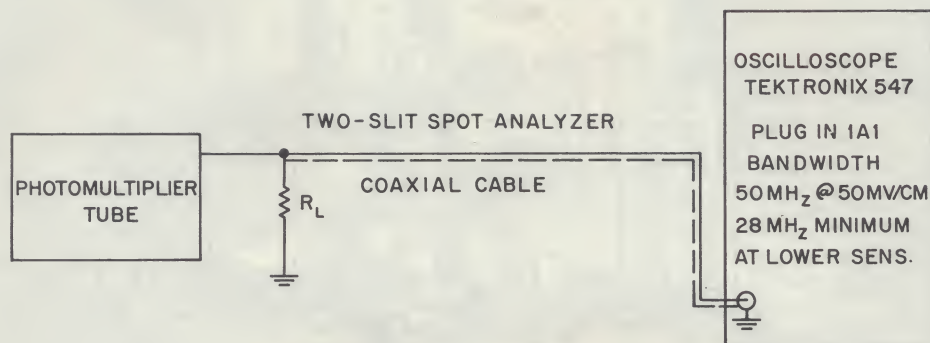


FIGURE 7.

PHOSPHOR LOADING=C

$$I_B = .185 \mu a$$

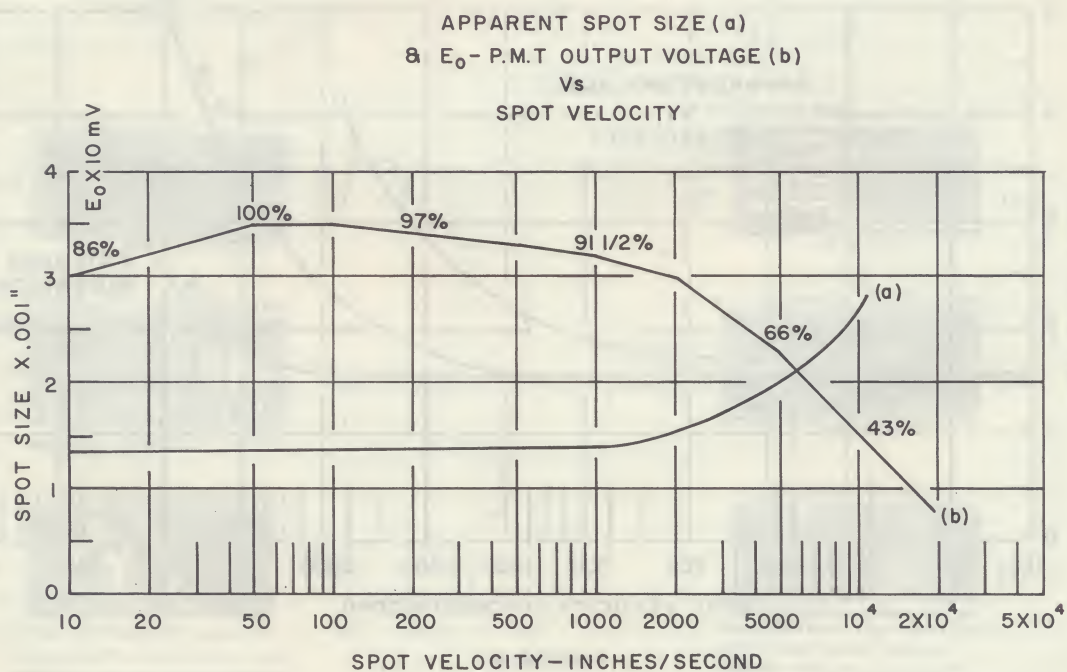


FIGURE 8